Figure 2: Average soil profiles for *Lepidium papilliferum*-slick spots and shrub interspace sites for the Simco Road, Kuna Butte, Tenmile Ridge *Lepidium* populations, displaying soil textures and average pH levels of sampled horizons.

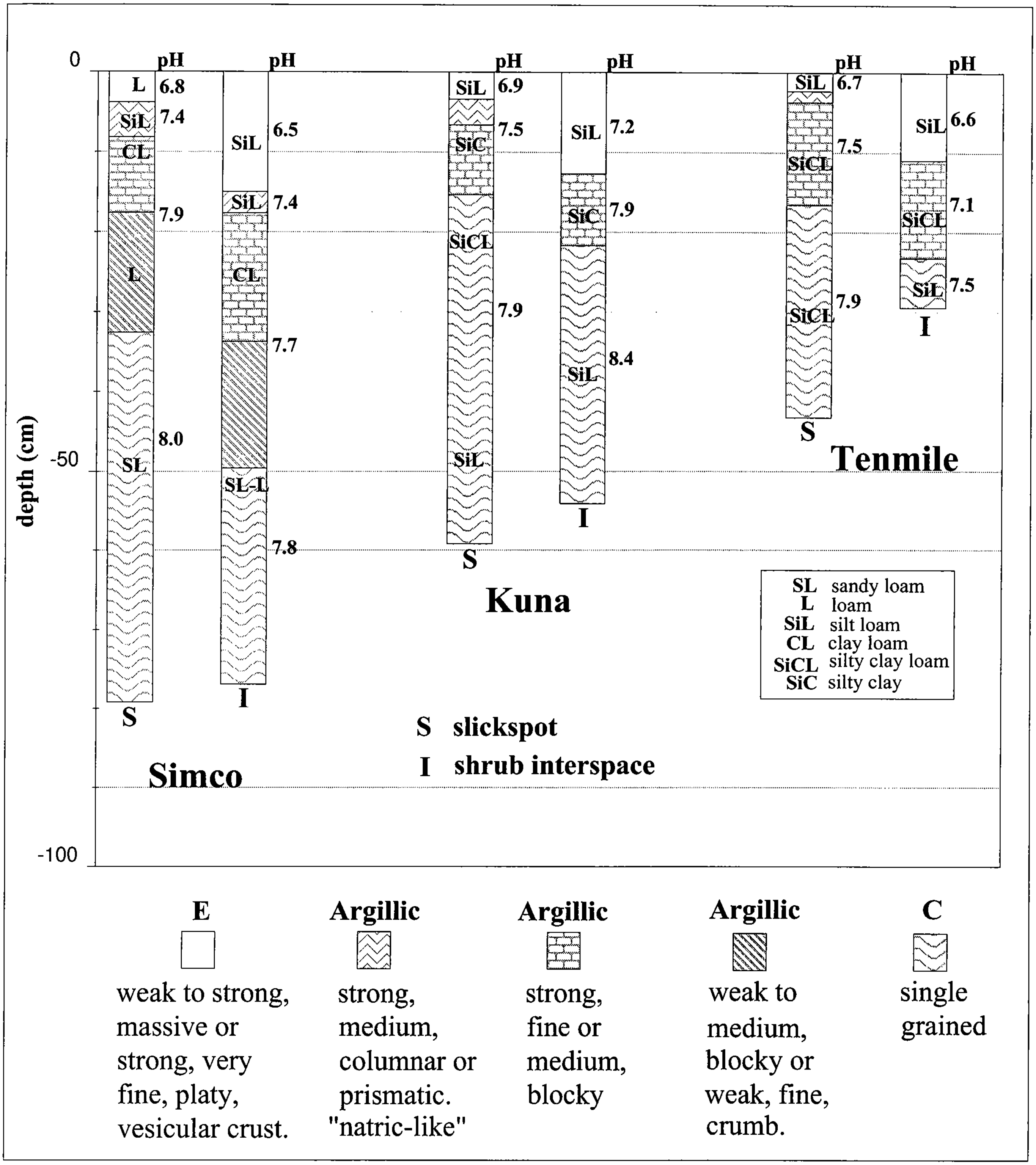


Figure 3: Average depth profiles of soil clay content for *Lepidium papilliferum*-slick spot sites and shrub interspace sites at Simco Road.

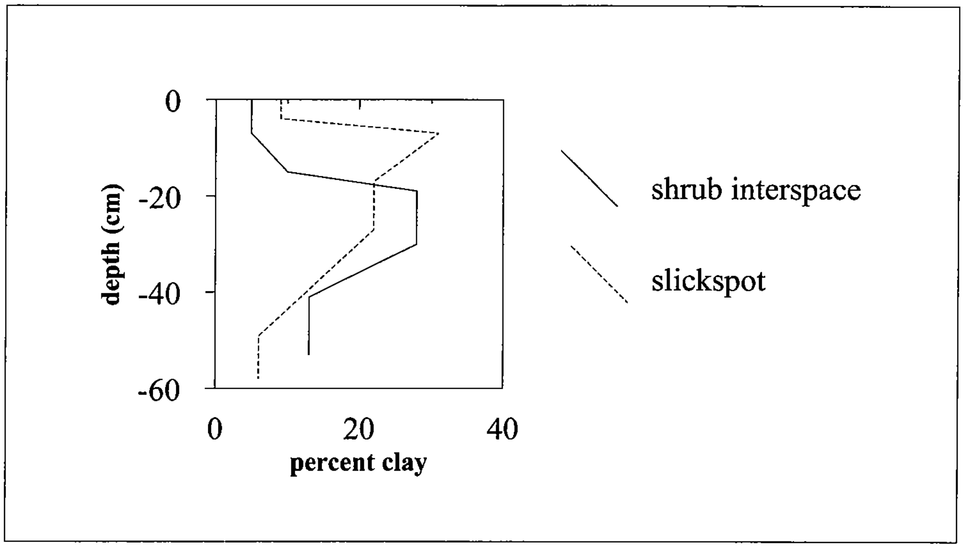


Figure 4: Average depth profiles of soil organic matter content for *Lepidium papilliferum*-slick spot sites and shrub interspace sites at Simco Road, Kuna Butte, and Tenmile Ridge.

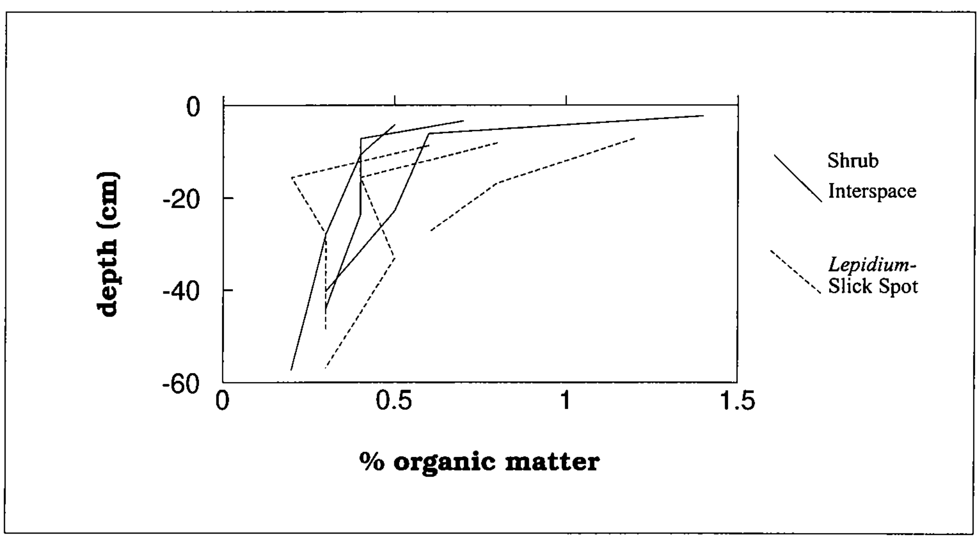


Table 3: Average depths and thicknesses (standard deviations in parentheses) of the argillic horizons for each population and site type.

Population	Depth to Argillic	Thickness of Argillic Layers	Depth to Surface of C Horizon
		Shrub Interspaces cm	
Tenmile	12 (5)	13 (6)	20 (4)
Kuna	13 (4)	22 (15)	23 (6)
Simco	15 (5)	33 (10)	48 (13)
		Slick spots cm	
Tenmile	3(1)	14 (3)	16(3)
Kuna	5 (3)	13 (3)	16 (1)
Simco	4 (2)	29 (13)	37 (16)

The abrupt crust-argillic boundary is always a feature of slick spot profiles, but may or may not occur in the soil profiles of shrub interspaces. At Simco Road, the clay content of *Lepidium* - slick spot profiles increases sharply by an average of 22% at the crust-argillic horizon boundary (Figure 3). Similarly abrupt increases in soil fines were identified by hand-textures of slick spot soils at the other locations. Clay pick-up on shrub interspace sites, however, is variable and at Tenmile Ridge there was neither an abrupt nor a large increase in clay accumulation in the shrub interspace profiles. At Simco Road, the argillic horizon of shrub interspaces was at least as abrupt and as well developed as for slick spot sites.

On all slick spots, the ped structure in the upper argillic horizon (Bt1) is columnar (long axes 2 - 5 cm) and sometimes domed on top (prismatic). By Soil Taxonomy rules, such structure is required for an argillic horizon for it to qualify as "natric", should the exchangeable sodium percentage also qualify as "sodic" (Nettleton and Peterson, 1983). The "natric-like" horizon of *Lepidium*-slick spot soils is thin, typically less than 5 cm in thickness. Below it, the structure is blocky and often comprised of fine crumbly, blocky peds described as "coffee grounds". "Natric-like" horizons also occurred in the shrub interspace profiles at Simco Road but not at the other locations (Figure 2).

Soil Profile Chemistry for *Lepidium*-Slick Spots and Shrub Interspaces

The pH levels of soil/water suspensions (Figure 2) reflect a downward movement of soluble salts through both slick spot and shrub interspace profiles. Crust and upper argillic horizons have slightly acid to near neutral surface pH levels. These increase with depth to alkaline levels of pH 8.0 to 8.5, reflecting the presence of calcium carbonate dissolution.

Electrical conductivity (EC) is another means of observing soluble salt eluviation and accumulation in soils. A soil is classified as saline if the electrical conductivity (EC) of the solution extracted from the saturated soil paste has a value >4 mmho/cm (Sposito, 1989). This particular level correlates with reductions in crop growth and yield by osmotically stressed plants. For example, the relatively salt-tolerant crested wheatgrass (*Agropyron cristatum*), perennial ryegrass (*Lolium perenne*), and beardless wild rye (*Elymus triticoides)* experience yield reductions in the order of 10 to 25% when grown in soils with EC ranges of 4 to 11 mmho/cm (Bohn and others, 1979). Soil salinity levels measured by EC are also useful in describing the distributions of distinctive plant communities that grow naturally on salt-affected soils. North Dakota pan soils with EC-levels that range from 2.8 mmho/cm at the surface to 13 mmho/cm at 110 cm depth support a community of *Agropyron spicatum*, *A. trachycaulum*, *Poa sandbergii*, *Atriplex nuttallii*, *Chenopodium glaucum*, *Polygonum aviculare*, *Ceratoides lanata*, and *Opuntia* spp.. Most of the same species persist in adjacent transitional soils but are absent from the surrounding non-saline soil (Hopkins and others, 1991).

The *Lepidium*-slick spot sites can be classified as saline. The first evidence of soluble salt accumulation is in the second-depth sample at the crust and upper-argillic interface (Table 4). Saline EC conditions (>4 mmho/cm) occur within the upper 10 cm of many *Lepidium*-slick spot profiles (Figure 5) and within 20 cm of the surface there are moderately high salinity levels, ranging from 6.9 (Kuna) to 11.8 mmho/cm (Tenmile). Soluble salts continue to increase with depth to an average of 14.1 mmho/cm for all slick spot C horizons. Although soluble-salt levels in the crusts are relatively low, the conductivity of very thin crusts are affected by higher salinity levels of the argillic horizon below.

By contrast, the shrub interspaces have significantly smaller accumulations of soluble salts. For each sampling layer, the differences between slick spot and shrub interspace EC-levels are highly significant (Table 4). At the Simco Road and Kuna Butte locations, there is some soluble salt accumulation in the subsoils but EC levels of argillic horizons are not saline (<4 mmho/cm). Soluble salts have not accumulated in the shallow shrub interspace profiles of Tenmile Ridge (Figure 5).

High salinity in arid-zone soils is typically caused by the relatively soluble Na, K, Ca and Mg cations. These are released into solution by primary mineral weathering. They accumulate near the soil surface, avoiding deep leaching when annual soil evaporation rates exceed precipitation rates, and they combine with secondary clay minerals or form carbonates, sulfates and chlorides. Chloride is the main soluble anion extracted from slick spot and shrub interspace soils (Table 4).

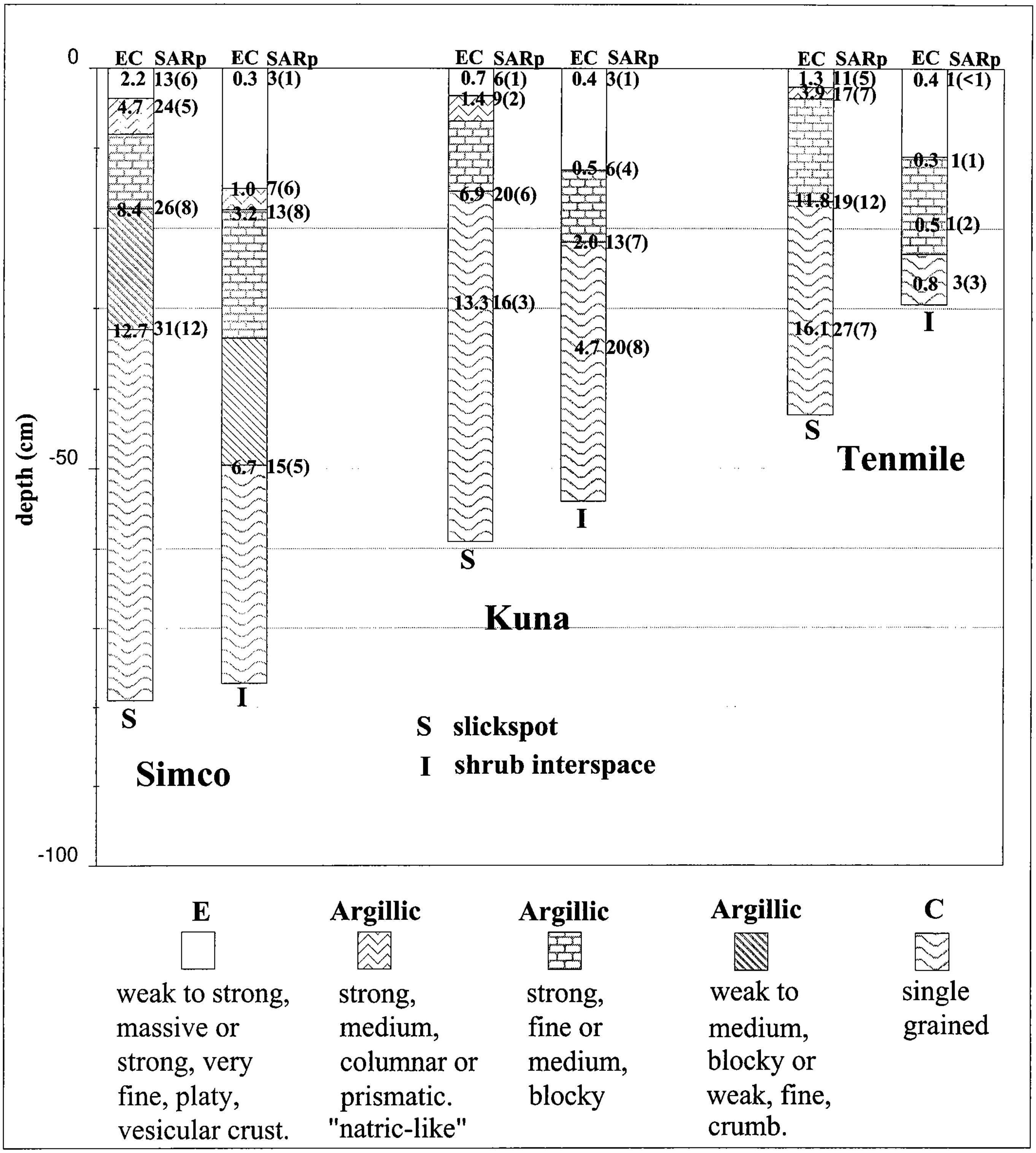
Soil properties are affected by both the ionic strength of soil solutions (related to EC) and by the relative composition of soluble cations in soil solutions. Exchangeable Na, Ca and Mg, in particular, affect the behavior of clay colloids in semi-arid soils. Higher concentrations of exchangeable Na relative to exchangeable Ca and Mg cause dispersion of clay aggregates into solution. This condition produces soils with lower porosity and lower water permeability.

A simplified index of the relative sodium status of soil solutions, the sodium adsorption ratio (SAR), is used to indicate the degree of sodicity of the soil exchange complex.

$$SAR_p = Na_T / (Ca_T + Mg_T)^{1/2}$$

where the subscript "p" indicates "practical" SAR and subscript "T" represents the total concentrations of soluble ions in the saturated-paste extract, given in mol/m^3 (equivalent to

Figure 5: Salinity (EC), and sodicity (SARp) profiles for *Lepidium papilliferum*-slick spot sites and shrub interspace sites within the Simco Road, Kuna Butte, and Tenmile Ridge *Lepidium* populations.



mmol/L) (Sposito, 1989). When the SAR_p is greater than 13, the soil condition is classified as sodic (sodium affected), implying the potential for clay dispersion and impaired soil permeability of fine-textured soils. There are also interactions of sodicity (SAR_p) with salinity (high EC), however, which affect the degrees of dispersion. As long as the EC level of the soil solution is low (below a critical aggregation concentration that depends on the kinds of clay minerals in the soil), high relative sodium concentrations will cause clay dispersion. But at higher EC levels, the clay minerals will tend to aggregate even when the SAR_p is high.

Sodium is the dominant soluble cation in the *Lepidium*-slick spot soils (Table 4), although the degree of sodicity varies among population locations. SAR_p values exceed 13 in the upper argillic horizons of both Simco and Tenmile *Lepidium*-slick spots, increasing with depth and salinity (EC) (Figure 5), and sodic conditions also occur within 20 cm of the surface of Kuna Butte *Lepidium*-slick spot profiles. The slick spots at all locations fulfill both requirements for a natric horizon, i.e., columnar or prismatic ped structure in some part of the argillic horizon and SAR levels > 13 within 40 cm of the soil surface (Soil Survey Staff, 1992).

The shrub interspace subsoils at Simco Road and Kuna Butte are also sodic but the soils are not saline and sodium concentrations are significantly lower than in the same *Lepidium*-slick spot layers (Table 4). Sodium does not dominate the cation exchange complex of Tenmile shrub-interspace profiles. The high sodicity and relatively low salinity that occurs just below the surface of slick spots probably accounts for the massive, platy orientation of silt particles above the crust/argillic horizon interface and for the observations of slow water permeability reported on slick spot soils (Moseley, 1994).

Edaphic Characteristics of *Lepidium papilliferum* Slick Spots

The very distinctive soil characteristics of *Lepidium papilliferum*-sites occur across all of the landscapes included in this study. *Lepidium*-slick spots are distinguished from the surrounding soils by very thin surface layers (epipedons) that form light-colored, prominently vesicular crusts and by the natric-like argillic horizons that occur just below the soil surface. Both high salinity and sodicity occur within the upper 40 cm of the profiles. The saline and sodic soil solution chemistry, the apparently truncated surface horizons of slick spots, and the near-surface argillic horizons conspire to produce smooth panlike surfaces, structureless and slowly permeable when wet, moderately hard and cracked when dry. In the surrounding soils, thicker epipedons and low salinity allow a more diverse microtography, a greater surface-soil rooting volume and crust conditions that are not so intimately influenced by the chemistry of the subsoil as they are on slick spots.

The consistency of these soil characteristics and the exclusion of most other plant species from slick spots suggests that edaphic factors have considerable bearing on where *Lepidium* grows. Similar slick spot-like crusts restricted seedling emergence and produced stress symptoms in seedlings of crested wheatgrass (*Agropyron cristatum*) and squirreltail (*Sitanion hystrix*). The strongly vesicular crusts were significantly harder than adjacent shrub coppice soils and apparently more resistant to forces produced by elongating roots than the latter soils (Wood et al.,1978).

Table 4: Saturated-paste solution chemistry for four distinctive horizons of *Lepidium papilliferum*-slick spot sites and shrub interspace sites. Analysis of variance showed highly significant differences between site types for each layer ($p<0.005$, for Layer A, Sum of Cation Charge; $p<0.0001$ for EC, Na, and Sum of Cation Charge for all other layers).

Soil Character-istic	Site Type	E Crust	E+Bt1 Upper Argillic	Bt1+Bt2 Argillic	C Parent Material
		mean (number of samples, standard deviation)			
EC mmho/cm 1/	slick spot	1.4 (27,1.3)	3.2 (25,2.1)	8.9 (27,4.4)	14.1 (24, 3.9)
	shrub interspace	0.4 (27,0.1)	0.6 (26,0.7)	1.8 (25,2.2)	5.1 (18,3.5)
Na^+ mmol/L 1/	slick spot	15 (27,16)	35 (25,22)	115 (27,71)	182 (24,57)
	shrub interspace	2 (27,1)	6 (26,8)	23 (25,39)	60 (18,47)
Sum of Cation Charge meq/L 1/	slick spot	21 (27,26)	47 (25,22)	171 (27,106)	315 (24,90)
	shrub interspace	7 (27,3)	11 (26,9)	35 (25,60)	93 (18,83)
Cl^- mmol/L	slick spot	-	29 (27,23)	-	-
	shrub interspace	-	3 (27,5)	-	-
SO_4^{2-} mmol/L	slick spot	-	5 (27,15)	-	-
	shrub interspace	-	1 (27,2)	-	-

1/ The p values were calculated using the General Linear Models procedure with the model PARAMETER=TYPE POPULATION(TYPE) SITE(POPULATION TYPE).